Aerosol Microphysics and Radiation Integration

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Award Number: N0001406WX20253
http://www.nrlmry.navy.mil/aerosol/
http://www.nrlmry.navy.mil/flambe/

LONG-TERM GOALS

This project works toward the development and support of real time global prognostic aerosol and visibility models for the benefit of the Department of Defense and civilian research communities. The Aerosol Microphysics and Radiation program was established to lend support to these models through the development of physical to optical transfer functions to bridge the gap between observables (in situ and satellites) and model quantities such as mass. Aerosol species currently included in the analyses are dust, pollution, biomass burning smoke, and marine sea salt. This work includes generation of source/sink functions, creation of bulk and theoretical optical parameterizations, investigation of microphysical transformations, and the primary validation of model electro-optical products. Goals range in intricacy from the creation of simple thermodynamic and microphysical parameterizations for use in models to the development of complicated error matrices for use in aerosol data assimilation.

Fundamental to this program is the development of consistent aerosol microphysical and radiation models for the Navy's two primary operational aerosol models, the NRL Aerosol Analysis and Predictions System (NAAPS) and the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®). Over the next several years it is the goal of this project to maintain these systems as the world leaders in EO prediction.

OBJECTIVES

This fiscal year the Aerosol and Radiation Integration Program had several diverse objectives. These include:

1) Aerosol Data Assimilation (Zhang): A significant challenge in applying satellite data to the data assimilations problem is that it requires unbiased or at least quantified bias observations. Using long-term statistics, we estimate the observation and background errors, and develop methods for data screening. Then, by using the quality assured satellite aerosol products such as MODIS aerosol product, we develop a near real time aerosol data assimilation system. For this fiscal year, our primary objective were: a) Derive a realistic over-ocean error matrix for MODIS aerosol optical depth retrievals. b) Generate a new level 3 aerosol optical depth product suitable for aerosol data assimilation. c) Incorporate these products into the Navy Variational Analysis System (NAVDAS) for implementation in NAAPS.

2) UAE2 analysis (Reid): The United Arab Emirates Unified Aerosol experiment was one of the most extensive atmospheric science program yet completed in Southwest Asia. Under the Aerosol

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Aerosol Microphysics and Radiation Integration**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,7 Grace Hopper Avenue,Monterey,CA,93943-5502**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Microphysics and Radiation program we are performing extensive analysis of this data set. FY 2006 our goals were to a) lead the investigation of dust microphysical to optical transfer function from this mission. b) Determine the degrees of freedom in dust particle size and mass scattering properties of common mode dust for differing source regions.

3) Radiation impacts (Bucholtz): To achieve one of ONR 322's programmatic goals to includes aerosol radiative feedbacks into meteorological forecast models, this project has undertaken the study of how aerosol particles can perturb the atmospheric energy budget. This fiscal year we had two objectives: a) Analyze the long range transport and the radiative effects of Southwest Asian aerosol species such as dust and pollution. b) Continue the development of a comprehensive airborne radiometer measurement system capable of measuring the impact of aerosol particles on local radiative transfer budgets.

4) Biomass Burning (Hyer): Currently employed biomass burning emissions algorithms are highly underdetermined. In order to improve the Navy's biomass burning algorithm, this fiscal year we worked to determine the sources of uncertainty in commonly employed biomass burning emissions estimation techniques. Our sub objectives were to: a) identify how uncertainties relate to limitations in the input data, and work to overcome these challenges. b) Begin development a new emissions model that is capable of leveraging all available information from input data, with the minimum possible sensitivity to variability in conditions which cannot be observed in real time. c) Transition the current navy smoke emissions model to milestone 1 for use in the operational version of NAAPS running at FNMOC.

5) Data Systems (Curtis): The amount of available environmental data is accelerating rapidly. In response, one program objective was to advance computer processing of near real time data streams in preparation of use in data assimilation.

APPROACH

Team members supported by this project include Jeffrey S. Reid (analysis), Anthony Bucholtz(radiation), Cynthia Curtis(Data systems), Edward Hyer (biomass burning, ASEE Fellow), and J. Zhang (data assimilation, UCAR Fellow). To complete project goals, this work requires the simultaneous study of modeled, remote sensing, and field data. Physically consistent sets of particle parameterizations are generated based on all three data sources.

The data assimilation task focuses on the use of the NOAA Near Real Time Rapid Processing effort ("bent pipe") data feed where MODIS level 2 and degraded level 1b is made available to NRL with only a few hours latency. To establish an optical depth data assimilation four distinct task areas need completion: (1) Conduct a careful error analysis of satellite products for over land and ocean aerosol products; (2) Estimate error statistics for both observation and background fields; (3) Develop an aerosol data assimilation system (in this case, NAVDAS) to include optical depth in the analysis field; and 4) Apply the aerosol data assimilation system in a near real time mode.

Analysis of UAE^2 dust properties focuses on the simultaneous filter, aerodynamic particle sizer and light scattering data collected at the Mobile Atmospheric Aerosol and Radiation Observatory (MAARCO). Aircraft data sets from the mission were also compiled and linked to the extensive network of ground stations. Similarly, the analysis of the long range transport of Arabian Gulf region aerosols focused on completing the gathering and analysis of evidence of the long range, eastward

transport of dust from southwest Asia halfway around the world to the west coast of North America. This evidence consisted of aerosol transport modeling, surface and airborne measurements, and compositional analysis. The analysis of the radiative effects of Arabian Gulf region aerosols focused on characterizing the radiometer measurements from the UAE^2 field campaign. The surface and airborne, solar and infrared, irradiance measurements during UAE^2 were carried out under extreme environmental conditions with heat and humidity at the limits of the operating range of the instruments. To accurately characterize the response of the UAE^2 radiometers under these harsh conditions, the development of a comprehensive radiometer calibration facility was begun in collaboration with the Naval Postgraduate School Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS).

The focus of the work on the development of a comprehensive airborne radiometer measurement capability was on the acquisition of commercially available, off-the-shelf instrumentation, originally designed for measurements from the surface, and the modification of these instruments to make them suitable for aircraft use. Testing and troubleshooting also continued of the CIRPAS Stabilized Radiometer Platform, a tool for keeping radiometers level in flight.

For the biomass burning component, the FLAMBÉ emissions model was applied to the NAAPS aerosol forecast system to identify the key uncertainties in current estimates of smoke aerosol emissions. From this data we evaluated the impacts of different input data and different model calculation schemes on emissions estimates and forecast accuracy. This required a balance of considerations of overall model performance at global scales with specific case studies of severe events.

WORK COMPLETED

Work completed under this program can be summarized as follows:

Data Assimilation (Zhang, Reid, Curtis):

(1) Completed the most thorough error analysis of over-ocean aerosol products.

(2) Estimated error statistics for both MODIS observation and NAAPS background fields.

(3) Developed an empirically corrected and quality assured over-ocean MODIS level 3 aerosol product that will be used in the aerosol data assimilation processes.

(4) Demonstrated test cases of over-ocean aerosol optical depth assimilation into NAAPS using NAVDAS.

Southwest Asia (Reid, Bucholtz):

(1) Completed intial analysis of UAE2 data and are preparing manuscripts for the peer reviewed literature.

(2) Finalized analysis of study of intercontinental transport of Sothwest Asian dust to North America.

Radiation(Bucholtz):

(1) Developed airborne broad band solar/IR flux capability

(2) Helped develop new community calibration facility at CIRPAS

Biomass Burning (Hyer, Curtis, Reid)

(1) Assisted with the transition of the FLAMBÉ fire detection and smoke emissions estimation system to FNMOC operations.

(2) Assisted with obtaining and implementing an operational (NESDIS) source for FLAMBÉ input data, previously obtained from U. Wisconsin – CIMSS.

(3) Performed a detailed evaluation of the impact of uncertainties in land cover information on FLAMBÉ emissions estimation.

(4) Evaluated limits to accuracy of FLAMBÉ emissions resulting from characteristics of input data.

RESULTS

This fiscal year we made great headway in our understanding of the fidelity of MODIS optical depth data, consider by most to be the best available and only reasonable choice for data assimilation. Through our extensive quality assurance program, we identified several biases that as of yet were undetected by the scientific community. First, MODIS optical depth algorithms are underestimating AOT at low wind cases and over estimating at high wind cases, which could be related to white foams and the increase in width of glint regions as near surface wind speed increase. This study also reveals that MODIS aerosol retrievals are strongly affected by wind speed near glint regions, while for glint angles larger than 80°, the wind speed effect is insignificant. Second, the MODIS cloud screening algorithm needs further tuning as the MODIS algorithm is also systematically overestimating AOT as cloud fraction increases. Cloud contamination introduces overestimation at low and high aerosol optical depth ranges. Lastly, our findings confirm that MODIS is underestimating AOT over smoke and pollutant aerosol regions and over estimating AOT over dust regions.

By introducing and applying empirical correction and quality control procedures, the absolute difference between SP (what is this?) and MODIS τ is reduced 10-20% on a global basis, but up to 50% in some regions. For example after applying empirical corrections and QA procedures, the aerosol plumes at the roaring 40's and some high northern latitudes off of the coast of China are significantly reduced, indicating cloud contamination and biases due to near surface wind speed patterns could be responsible for a large portion of the high aerosol optical depth plumes observed over these regions.

Using this new level 3 product, we have performed test data assimilation runs with NAAPS. Figure 1 shows the preliminary result of data assimilation using the over-ocean MODIS aerosol product. Figure 1a shows the original 5 day forecast for July 15, 00:00 UTC to July 19, 18:00UTC, 2004. Dust and biomass burning aerosols from Africa are clearly seen. Figure 1b is the 3-day composite (July 17-19, 2004) to provide a general pattern from an observational perspective. Different from Figure 1a, a large aerosol plume is observed over northern America. Identified from MODIS level 1B imagery, the huge plume originated from forest fires over high latitudes of the Northern Hemisphere. In NAAPS, smoke aerosol plumes are predicted based on hot spots detected by MODIS and GOES satellites, though some fire sources could be under clouds and not detected by satellites. Figure 1c shows the result of 5-day assimilation run with MODIS data assimilated into the system every six hours. Figure 1c shows a similar pattern to Figure 1b, with the smoke plume over North America detected. To demonstrate the sensitivity to using the previous un-QA satellite product, Figure 1d shows an example of one erroneous

retrieval being used over southern hemisphere, which has a large negative impact on the assimilated result. Indeed, the data assimilation system is very sensitive to bad observations.

For our research on Southwest Asian aerosol particles, we explored the evolution of dust particle size distribution in the atmosphere and how such changes impact their optical properties Preliminary evidence suggests that it is the inherent properties of the source region (e.g., mineralogy, saltator load, surface roughness) that dominate the particle distribution, rather than meteorological variables such as wind speed or deposition characteristics. Regarding our studies on transport phenomenology, a more in depth analysis of the evidence has confirmed the long range transport of dust from southwest Asia to the west coast of the United States in March 2003. No one piece of evidence was conclusive, but the combination of the following findings is highly suggestive: 1) a high resolution mesoscale model shows dust from southwest Asia and northeast Africa being transported as far east as Japan, 2) a global aerosol model shows the dust arriving on the west coast of the U.S., 3) met surface observations in China do not report any significant dust storm activity, and 4) surface and airborne measurements on the west coast of the U.S. indicate the presence of aerosols and dust on the predicted arrival date of the dust from southwest Asia.

Regarding biomass burning, our efforts have shed light in the use of landcover maps to help monitor burning emission. We found that static land cover data, currently standard in almost all smoke emissions models, produces serious bias in estimated emissions. In regions of active land cover change, these biases can exceed 40% over five years. Further, precision of spatial information from current satellite fire detection systems is insufficient for accurate characterization of fuels. Accurate, unbiased description of fuel characteristics in heterogeneous landscapes requires ancillary data.

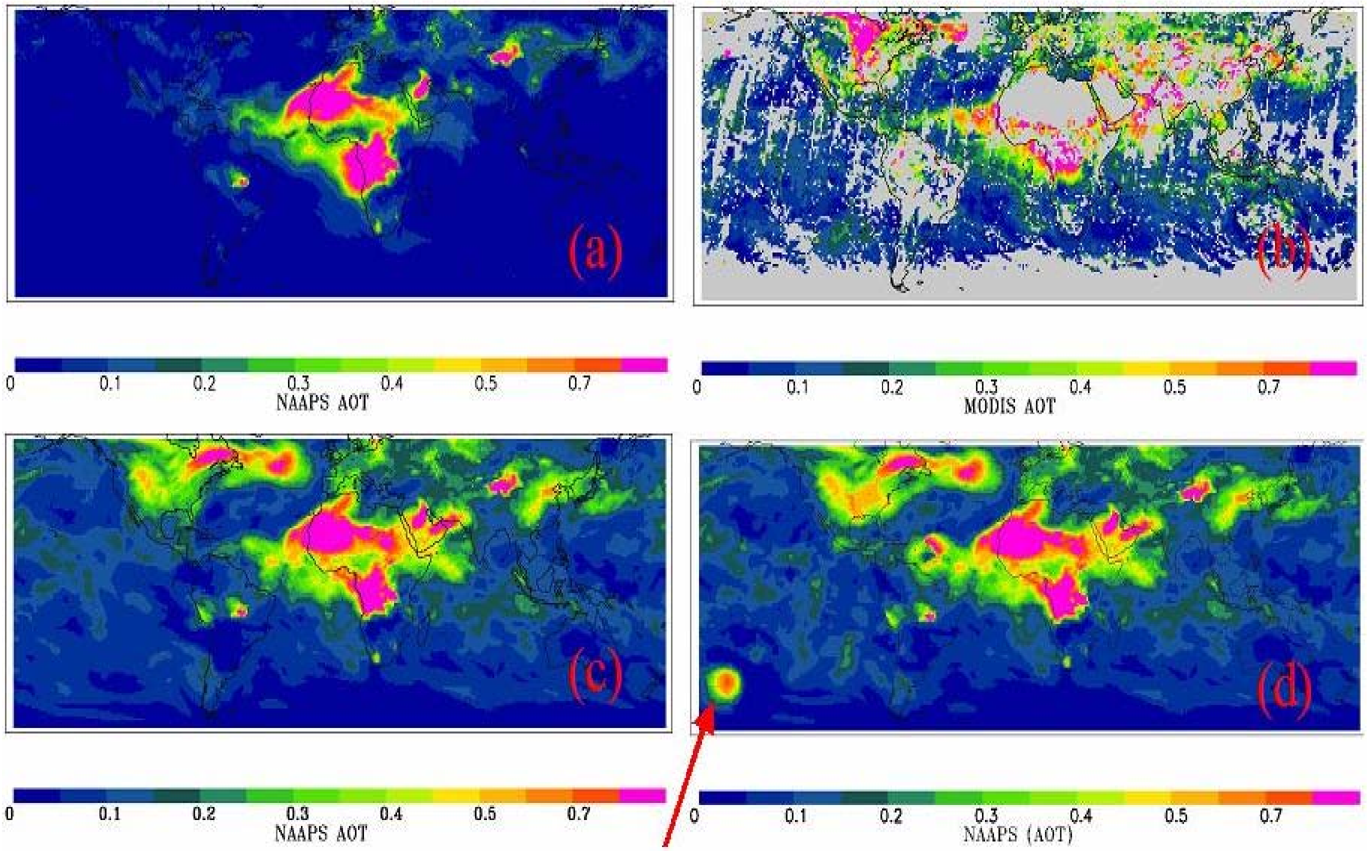

Figure 1a) NAAPS five day run from July 15, 00:00UTC to July 19, 18:00UTC, 2004; b) MOD04 three day composite (July 17-19, 2004); c) Five day assimilation run from July 15, 00:00UTC to July 19, 18:00UTC, 2005. MOD04 data is assimilated into the system every 6 hours; d) Example of an erroneous retrieval is being used over southern hemisphere.

IMPACT/APPLICATIONS

The most significant impact of this program to the Navy this year is that the first phase in developing an operational aerosol data assimilation system was completed with the creation of a near real time levle 3 aerosol optical depth product. This work will eventually yield the world's first operational aerosol optical depth data assimialtion system. We expect this advancement to greatly improve the DoD's ability to monitor and forecast severe visibility reducing events. The development of this system has also lead us to greater understanding of long range transport patterns around the globe, as well as to the detection of significant systematic biases in previous global aerosol datasets commonly in use in the scientific community.

The continued collection and analysis in the Southwest Asian theater has allowed the contruction of a regional database of environmental information. This database is not only useful for basic research, but when completed will provide EO/EM engineers with the information they need to evaluate system performance.

Regarding biomass burning, the results of the work performed this year laid the groundwork for improvements to the FLAMBÉ system that are already underway. The results obtained this year were

necessary to establish priorities and set a baseline of performance for FLAMBÉ by which this year's improvements can be measured.

TRANSITIONS

All source functions and microphysics products feed directly into NAAPS and COAMPS® aerosol modules. As these models have been transitioned to Fleet Numerical Oceanographic and Center (FNMOC) for Navy operational visibility forecasting, associated prodcuts are being transitioned as well. Processed data collected in the UAE[2] will be made available to other DoD organizations for validating and improving EO propagation models.

Fire products (including fluxes and transport data) from the joint ONR 32/NASA Fire Locating and Modeling of Burning Emissions (FLAMBE) project will in the next month transition to the Fleet Numerical Oceanographic Center (FNMOC) Monterey.

RELATED PROJECTS

This project is closely tied to other work units at ONR Code 35, NRL, NPS, and NASA. Products, data assimilation code and validation work feed directly into the ONR 32 6.2 project Coastal Aerosol Distribution by Data Assimilation (Douglas L. Westphal, PI) for further development of NAAPS as well as 6.1 Base funding projects developing an aerosol componeent to COAMPS® (Ming Liu, Shouping Wang). Systems developed under this work unit are being immediately applied to the ONR 35 project on directed energy propagation. Field measurements collected in FY04 in the Arabian Gulf region and analyzed in FY05 and FY06 under this work unit are being used in COAMPS® and NAAPS model assessment (Westphal, Holt). Near-real time remote sensing products are also utilizing this work unit's products.

Outside the Navy, products and paramterizations receive heavy usage from NASA and the air quality communities as well as a broad base of researchers.

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